Mars 2020 Surface Mission Performance Modeling: Part 3. Mission Performance Modeling Approach and Results

Robert D. Lange[1],
NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, USA

Travis L. Wagner[2],
NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, USA

Sarah M. Milkovich[3],
NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, USA

and

Masahiro Ono[4]
NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, 91109, USA

We have developed a comprehensive model of the Mars 2020 rover surface mission used to identify and evaluate mission productivity and operability challenges and opportunities. The *surface mission performance model* combines many aspects of rover design, operations approach, system behaviors, and mission constraints into an integrated model of surface mission performance. The surface mission model applies monte-carlo methodologies in order to investigate the key sources of mission performance variability and their effects with respect to overall mission performance. Our modeling efforts aims to investigate and inform engineering design and development efforts, as well as the landing site selection process led by the Mars science community. We believe that an integrated mission performance model such as this is important to aligning engineering and science efforts across the project.

Nomenclature

BRS	=	Baseline Reference Scenario
L1	=	Level-1 Project Organization Heirarchy, ie Project Management
L2	=	Level-2 Project Organization Heirarchy, ie Project Subsystems
L3	=	Level-3 Project Organization Heirarchy, ie Subsystem Functional Groups
LMST	=	Local-Mean Solar Time
LTST	=	Local-True Solar Time
MSL	=	Mars Science Laboratory
MY	=	Mars Year(s)
Sol	=	Mars day

I. Introduction

THIS paper is *Part 3* of a paper trilogy that together provide a detailed account of the various aspects of mission modeling and simulation towards Mars 2020 mission performance evaluation efforts. Each paper is intended to be stand-alone and complementary to communicating the full scope of surface mission modeling developed for Mars 2020 Mission Planning.

[1] Mars 2020 Mission Planning Lead, Group 394A, Mail Stop 321-400
[2] Mars 2020 Mission Planning Engineer, Group 394A, Mail Stop 321-400
[3] Mars 2020 Science Systems Engineer, Group 394B, Mail Stop 321-400
[4] Robotics Technologist, Group 347E, Mail Stop 198-219

The related papers at the AIAA Space Forum 2017 are titled *Mars 2020 Surface Mission Performance Modeling:*

Part 1. Science Exploration and Sol Type Modeling

Part 2. Surface Traversability

Part 3. Surface Mission Performance Modeling and Results (you are here)

II. Mars 2020 Mission Introduction

The goals of NASA's Mars Exploration Program are to determine if life ever arose on Mars, to understand the history and evolution of the planet, and to prepare for future human exploration. Progress toward these goals is accomplished through a systematic exploration of Mars by robotic spacecraft that seek to understand the current state and evolution of the planet through remote sensing, in situ analyses, and potentially, the return of Martian samples to Earth.

The Mars 2020 project plans to launch a rover to a single location on Mars in the July - August 2020 launch opportunity as a part of the NASA Mars Exploration Program. The successful landing of the Curiosity rover on August 6, 2012 was the latest in a series of technological and scientific triumphs of NASA's Mars Exploration Program. As our knowledge of Mars grows, it is becoming increasingly evident that habitable conditions formerly prevailed on the Martian surface. Major uncertainties remain, such as when and where those conditions prevailed, whether some form of life ever took hold, and if so whether any evidence of it has been preserved. The next logical steps are to identify and explore areas suspected of former habitability and look for evidence of past life.

The Mars 2020 Project is a strategic mission that will advance the scientific priorities detailed in the National Research Council's Planetary Science Decadal Survey, entitled *Vision and Voyages for Planetary Science in the Decade 2013-2022*[1] with specific mission objectives as described in the NASA *Announcement of Opportunity, Mars 2020 Investigations*[2]:

1. **Geologic History** Carry out an integrated set of spatially-coordinated context and contact measurements to characterize the geology of the landing site
2. ***In Situ* Astrobiology** Find and characterize ancient habitable environments, identify rocks with the highest chance of preserving signs of ancient Martian life if it were present, and within those environments, seek the signs of past life
3. **Select, Collect and Cache Samples** Acquire and cache a suite of rigorously documented and returnable samples for possible future return to Earth
4. **Facilitate future human & robotic exploration** by helping fill in Strategic Knowledge Gaps (such as assessing local natural resources or potential hazards for future human explorers) and demonstrate new technologies and concepts of operation

The Mars 2020 Project will accomplish the above objectives by landing a single mobile science laboratory on the surface of Mars. The M2020 project will use the proven design and technology developed for the 2011 Mars Science Laboratory (MSL) mission and rover (Curiosity) that arrived at Mars in August 2012. This is a key element of Mars 2020 flight system development planning; entire systems, and many elements of the rover system will be inherited from MSL without change.

The Mars 2020 rover will be outfitted with new payload elements to meet the described science objectives and human exploration measurement goals. In order to explore the geology and assess the habitability of an astrobiologically relevant ancient environment on Mars, the capability to conduct lateral and stratigraphic surveys and analyses at multiple spatial scales on many targets is required.

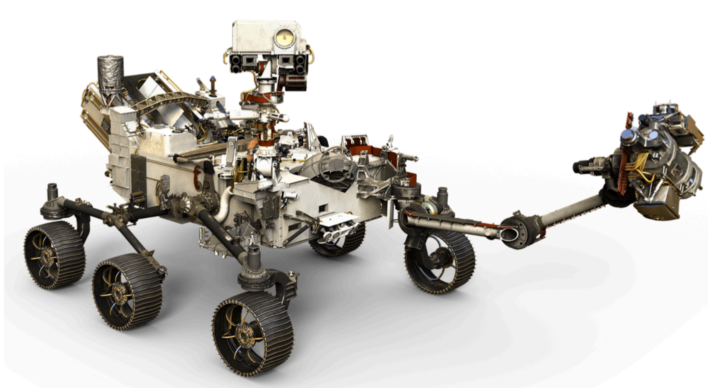

Figure 1. Mars 2020 Rover. *Computer rendering of the current Mars 2020 rover design with robotic arm unstowed and extended.*

In addition, the Mars 2020 rover will be equipped with a newly design Sample Caching System designed to collect up to 43 Martian rock and/or regolith samples, process and store those samples in individual hermetically sealed tubes, and depositing the collected sample on the surface of Mars for future missions to potentially retrieve the samples and bring them to Earth for further study.

More information regarding the science exploration goals of the Mars 2020 mission can be found in Part 1 of this paper series, entitled *Science Exploration and Sol Type Modeling*.

III. Surface Mission Performance Modeling Approach

The Mars 2020 mission performance model can be viewed as a bottom-up model consisting of four main elements. The four elements are:

1. *Rover Activities* - Payloads and Engineering subsystems provide resource consumption estimates for expected, typical operational use cases, called Activities. Payload Activities and their resource models are are encoded into MSLICE via the Activity Dictionary
2. *Sol Types* - Activities are scheduled into Sol Types and modeled in MSLICE, allowing for detailed resource modeling. Sol Types are designed to fit within resource constraints and perform essential operations towards a particular science or engineering objective
3. *Science Exploration* - Science Exploration at landing site ROIs is expressed as a set of ratios of Sol Types. These ratios are determined by Science Office after researching MSL science campaign examples and interpreting M2020 mission objectives.
4. *Surface Mission* - A surface mission is assembled by combining together Sol Types according to ROI Exploration ratios, surface mission characteristics, and orbiter relay configuration. This allows for estimation of overall mission performance for values such as mission duration, sols-per-sample, science campaign execution, and so forth.

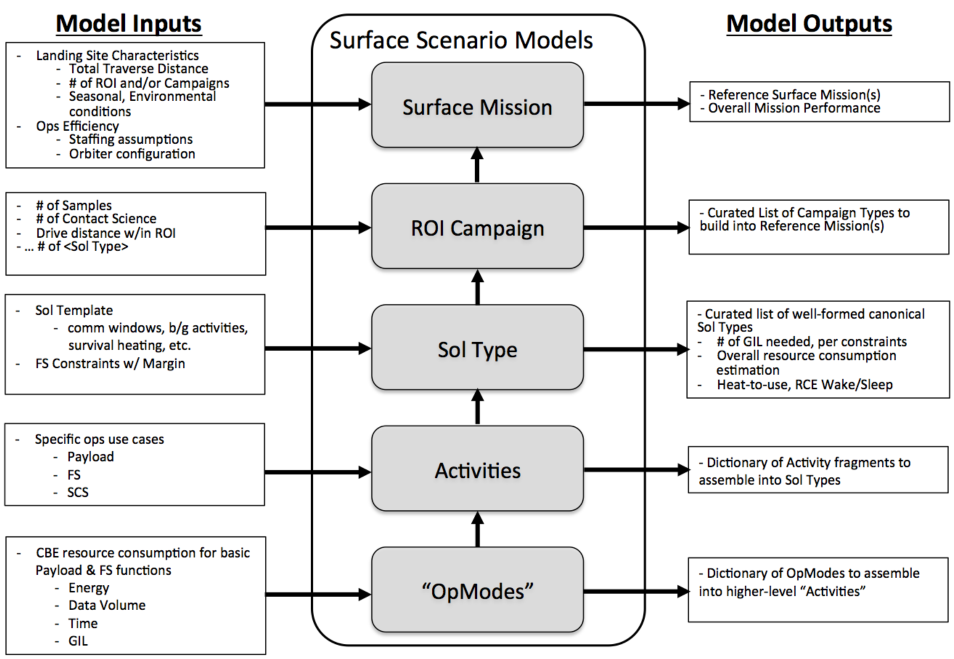

Figure 2. Surface Mission Performance Model Overview.

This scenario-based bottom-up mission modeling approach provides several important benefits early in the Project lifecycle. First, it gives focus to design and development efforts on vehicle operability and promotes a philosophical imperative for operability. The process of creating rover operational scenarios cultivates mission/sol scenarios based on both science and engineering inputs. The scenario design process also helps to identify project-wide productivity and operability challenges and opportunities, for which the Project can determine the appropriate priority and response. The scenarios and mission modeling helps to evaluate conceptual and technical trades for quantitative metrics on impacts to mission performance.

IV. Baseline Reference Scenario

Mission performance requirements are measured against a "Baseline Reference Scenario" (BRS). The BRS is a fictional mission which is defined as a Level-2 Project requirement in such a way that it serves as a good representation of a typical Mars 2020 surface mission. The BRS mission is intended to be stressing or bounding in its definition. The BRS is not real but is informed by expected mission operations characteristics. The BRS is used to drive key Level-3 and Level-4 capability requirements needed to accomplish mission objectives. The BRS serves as our benchmark.

The BRS mission is defined as follows:

> The project system shall have the capability to perform the following Baseline Reference Scenario (BRS) surface mission within 1.25 Mars Years (836 sols), which includes the following:
>
> - Conduct the investigations required to meet science objectives A and B and meet technology objective D
> - Explore 2 distinct Regions Of Interest (ROI) of approximately 1 km x 1 km area.
> - For each ROI:
>   - 6 km of long traverse to reach
>   - Conduct 2 science Campaigns per ROI
>   - Investigate 5 stratigraphic Units per ROI
>   - 1.5 km of local traverse to explore, consisting of:
>   - 500 m “walkabout” driving per Campaign
>   - 500 m driving between Campaigns
>   - Acquire 9 cached samples per ROI, consisting of
>   - 7 Rock and/or Regolith samples
>   - 2 Witness Blanks
> - Acquire [2] rock and/or regolith “waypoint” samples at any point during the mission
> - Deposit the sample tubes at a single Cache Depot at a location near ROI #2

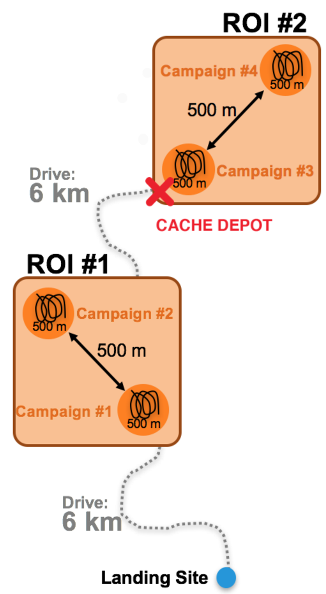

Figure 3. Baseline Reference Scenario. *Basic depiction of generalized Mars 2020 surface operations scenaio.*

In addition to the explicit mission parameters defined by the L2 BRS requirement, the performance model makes additional assumptions relative to mission characteristics that are necessary for understanding surface mission performance. For example, we assert two types of surface terrains encountered during drive campaigns between ROIs such that effective drive speeds vary more realistically.

A. Mission Duration Margins

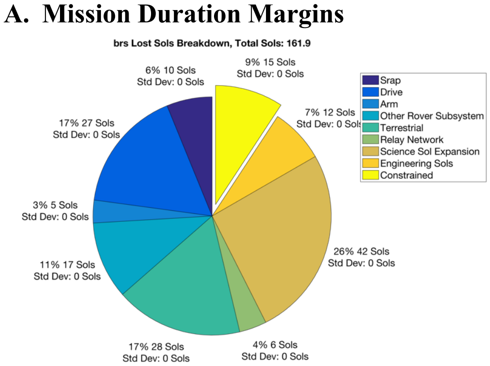

Figure 4. Baseline Reference Scenario Modeled Margins. *Breakdown of mission margin categories and corresponding number of sols modeled for the BRS mission case.*

Our model also seeks to model appropriate margin against expected faults, or “lost” sols that are unproductive towards mission objectives. We consider sources of “lost” sols such as command errors, minor anomalies, and plan/schedule expansion. Mission margins are implemented in the model such that margin sols are accrued as a rate, rather than constant margins, so that shorter mission result in fewer lost sols, and similarly longer missions result in more margin. The goal is to bookkeep margin as additional mission duration and compare the total amount of margin against Level-3 Mission System margin allocation of 0.25 Mars Year (MY), or 167 sols, within the 1.25 Mars Year duration specified by the BRS. We refer to this as ‘encumbered’ margin because it accounts for expected faults. Fault categories and the corresponding number of margin sols resulting from BRS mission parameters are given in Figure 4.

Along with expected faults, the model makes allowances for days when the rover cannot be commanded by the ground operations team. This occurs during major holidays when ground operations personnel are not staffed or during solar conjunction. Solar conjunction is when the Sun-Earth-Mars angle is less than 4-degrees, and a command moratorium is imposed because the sun blocks and corrupts radio signals to/from spacecraft at Mars.

Finally, on top of the 1.25 MY BRS mission duration the Mars 2020 Project (L1) also carries an additional 0.25 MY of 'unencumbered' margin. This is mission margin that is intended to account for major operational anomalies and or vehicle capability development uncertainty that could somehow affect surface mission performance. We do not model this portion of margin.

The timeline illustration below depicts how the different margins fit into the overall mission duration.

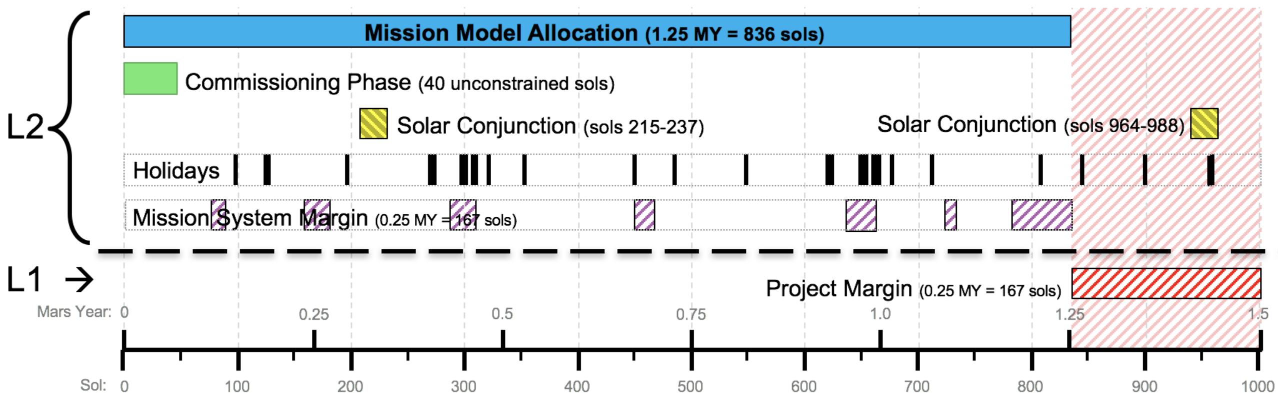

Figure 5. Mars 2020 Mission Timeline. *High-level timeline reflecting the major mission durations and allocation of margins, major holidays, and solar conjunction periods of the planned Mars 2020 surface mission timeframe.*

B. Baseline Reference Mission Performance Results

Results of Mars 2020 Baseline Reference Scenario performance modeling in support of Surface Phase Critical Design Review held in February 2017 are:

- BRS mission completes within 1.25 MY (836 sols)
- Requires 84% Ops Effieiency (see Section V)
- Employs Sol Type scenarios
- Includes all science investigation and required sample collection
- 19 km driven
- Includes L2 mission margins (does not include Project unencumbered margin)
- 40 sols rover commissioning phase included
- Assumes "Bin 3" landing site environment (see section VI for more information)

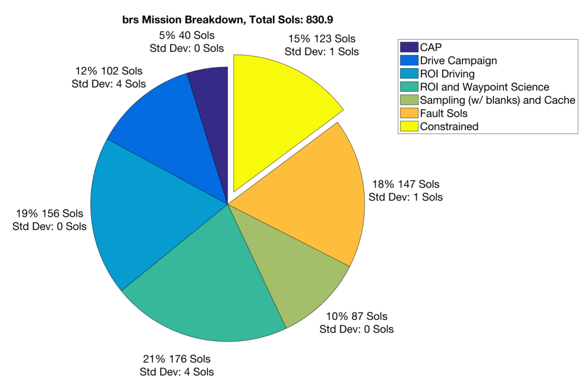

Figure 6. Baseline Reference Scenario Performance Results. *Breakdown of BRS mission sol counts by major mission phase.*

V. Relay Orbiter Simulation

Another aspect of mission performance that we model is the effectiveness of Mars orbiters to support relay of critical rover data back to Earth. Rover operations are a day-to-day activity where the Earth planning team, scientists and engineers, require new data from the rover in order to make informed decisions about how to command the rover. For planning purposes we assume that Mars 2020 surface operations will nominally have two orbiters available to relay rover data back to Earth for operations planning.

As with currently operating Mars rover missions, Mars 2020 plans to utilize the Mars Reconnaissance Orbiter (MRO) for low-latency relay of critical rover data needed for day-to-day rover operations decision making. A newer relay asset that may also be available for Mars 2020 surface operations is the Mars Atmosphere and Volatile Evolution (MAVEN) orbiter mission. However there is uncertainty in MAVEN's orbital elements during the Mars 2020 surface operations timeframe. Therefore we need to study several potential MAVEN orbits in order to assess their effectiveness as a relay asset in support of Mars 2020 surface operations. We have collaborated closely with Mars Exploration Program office to adapt existing simulation tools in order to investigate sensitivity to Mars orbiter relay support for many different orbiter configurations.

Our adaptation of orbiter simulations evaluate for two types of information; (1) Relay window data volumes, and (2) Ops Efficiency.

A. Orbiter Relay Data Volume Modeling

The first measure of relay orbiter performance is data volume throughput. Data volume predicts are computed based on orbital elements and high-fidelity telecom link models. We compare predicted data throughput against the data generated by the rover from the sol scenarios that we used to build mission performance models. This allows us to evaluate if a given orbiter configuration will meet the data volume needed for expected mission performance.

B. Orbiter Ops Efficiency Analysis

The second measure of relay orbiter performance we call *Ops Efficiency*, which is defined to be the ratio of unconstrained planning sols to the number of total sols planned in the surface mission. In other words, Ops Efficiency is the percentage of ground-in-the-loop commandable sols in the mission, and tells us how often the ground operations team is able to plan a new sol of rover activity with knowledge (data) from the previous sols. Ops Efficiency is governed by a number of factors, some of which are related to human-factors and operations team staffing constraints. Ops Efficiency modeling accounts for the following constraints:

- Orbiter relay pass timing and cadence (based on orbital elements and rover surface location)
- Relay link telecom performance (high-fidelity telecom model)
- Relay data return latency and data availability for planning
- Decisional relay window minimum data volume threshold
- Uplink planning cycle duration
- Work-day shift start/end time constraints and weekend staffing options
- Earth-Mars day phasing (approximately 37-sol per 38-day cycle)
- X-band uplink window timing
- Holidays and Solar Conjunction

Recall that for BRS mission analysis, we determined that an 84% Ops Efficiency is needed to complete mission objectives within allowable mission duration of 1.25MY. Our modeling shows that for assumed two-orbiter relay scenarios, we are able to achieve the necessary 84% Ops Efficiency for any MRO and MAVEN configuration given 7-day per week operations, 5-hour uplink planning cycle duration, while taking into account major holidays and solar conjunction. However, data volume relay throughput performance have been shown to be acceptable for only a subset of MAVEN orbit configurations.

VI. Site-Specific Mission Performance Modeling

Thus far we have discussed the modeling approach taken for the fictitious Baseline Reference Scenario mission, which is intended to be a stressing mission used for engineering analysis and to drive mission development in terms of capability requirements and vehicle performance. The BRS mission, however, does not give insight into the potential operational benefits and/or problems of individual landing sites. The modeling we have developed is parameterized in such a way that it can also be "tuned" to match the mission characteristics presented by actual candidate landing sites. Therefore, we apply the same modeling methodologies developed for the BRS mission onto the 8 candidate landing site in order to evaluate potential performance challenges or opportunities that are inherent to the landing sites, and to determine if vehicle design is adequate to accomplish mission objectives. Moreover, the modeling can accept a range of values for any mission parameters, and we employ monte-carlo methodologies in order to perform a parametric statistical evaluation. There are four dominant sources of mission variability that we evaluate in order to investigate site-specific mission performance:

A) Surface traversability
B) Science exploration locations and objectives
C) Landing site environments
D) Sol Type performance

A. Surface Traversability

Surface Traversability analyses are not discussed in this paper, instead the related AIAA Space Forum 2017 paper titled *Mars 2020 Site-Specific Mission Performance Analysis: Part 2. Surface Traversability* provides details into this portion of the mission performance modeling efforts.

B. Science Exploration Locations and Objectives

Also covered in the accompanying *Part 2* conference paper are details of the science exploration locations for each candidate landing site which have been identified by landing site proposers. These locations provide traverse path planning destinations that feed into surface traversability analyses.

Each science exploration location also has a corresponding set of science objectives, again provided by landing site proposers. Details of the science objectives and how they are modeled can be found in *Mars 2020 Site-Specific Mission Performance Analysis: Part 1. Science Exploration and Sol Type Modeling*.

C. Landing Site Environments

Our performance model also aims to quantify the operational variability that results from the seasonal environments of the 8 candidate landing sites. The landing site are at different latitudes and so experience different seasonal temperature variations and corresponding diurnal temperature curves. Using a Mars Global Climate Model (GCM) developed at JPL, local true solar time (LTST) ground temperature simulation data for all eight landing sites was generated over one Mars year, presented in the Figure 7 below.

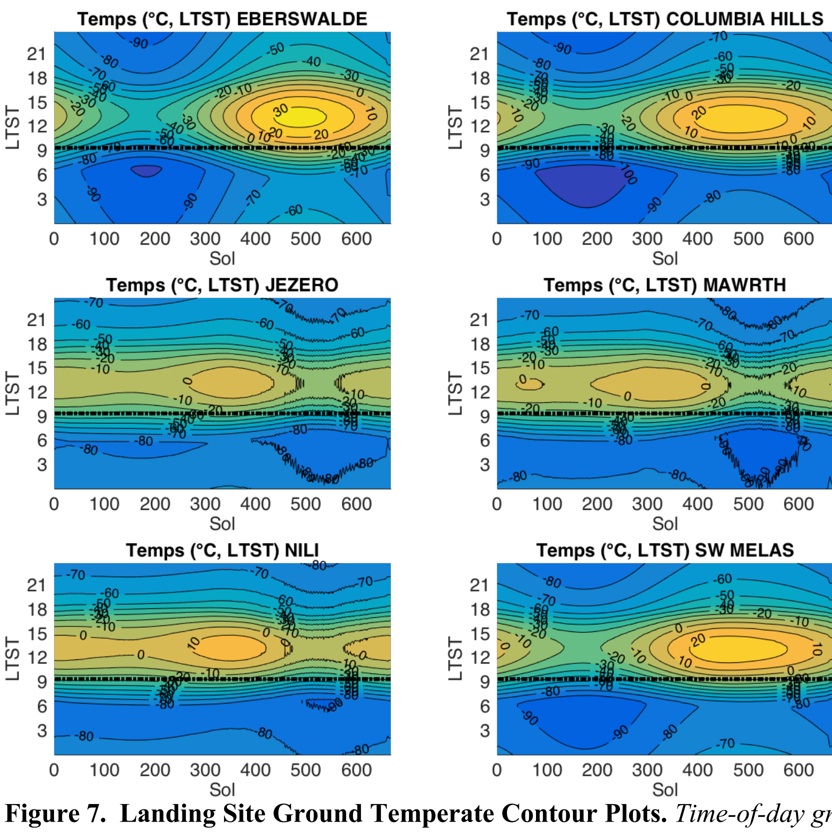

Figure 7. Landing Site Ground Temperate Contour Plots. *Time-of-day ground temperature as a function of mission sol over 1 MY, for each of the eight candidate landing sites.*

These temperature contours inform several variables that affect overall mission performance. Colder temperatures require increased rover energy expenditure due to increased survival heating and heating required to use the various instruments and subsystems. Additionally, some subsystems may have design constraints that cannot be mitigated using onboard heaters, and thus the allowable operational temperature ranges are constrained. The heating demands and operational constraints for a given diurnal temperature curve (i.e. environment) can be predicted via detail thermal modeling.

Heating on MSL is handled by the thermal team who first pick a representative diurnal curve for a given season at Gale (MSL's landing site) and then model the various subsystems and instruments to produce a table of heating values. Due to the large amount of work required to model heating values, these values couldn't be produced for every diurnal curve across each landing site and so an algorithm was developed to optimally discretize the thermal data into six thermal bins. The data was sliced at 9:30 am LTST at each of the landing sites and fed into the optimization algorithm. This time of day was chosen since it provided a good representative time where most of the preheating would happen based on MSL's operational cadence. The problem was formulated as a multidimensional optimization problem and the solution space was sampled at progressively higher and higher resolution, restricting the bounds of the solution space each time until the best integer temperature values for the bins were found. Along the way, solutions were scored using the R^2 measure of fitness to the data. To ensure that the more thermally extreme sites were being well matched, the scores were multiplied by a weighting factor derived from the variance of the data at each landing site.

Figure 8 below shows how each Mars 2020 candidate landing site is discretized into the six optimal thermal bins according to our algorithm. In addition, Gale crater is included here as a point of reference back to MSL's operational environment.

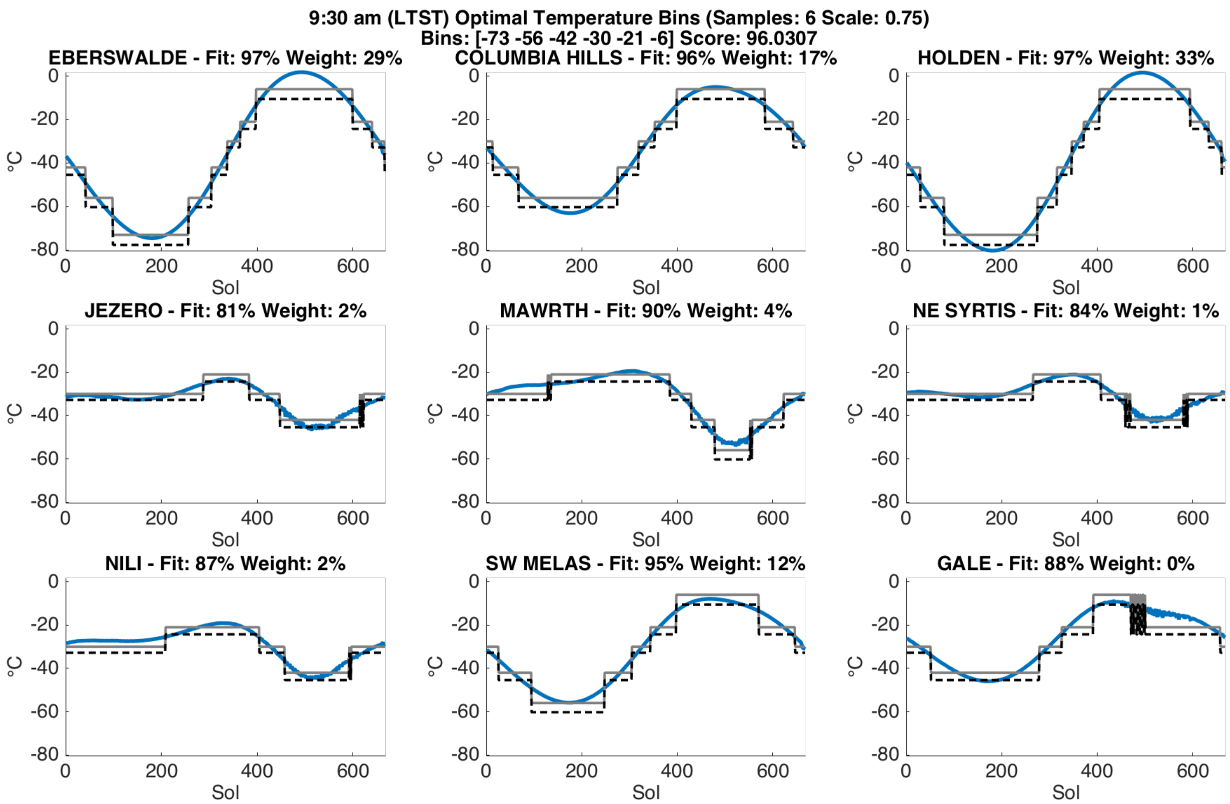

Figure 8. Landing Site Optimal Temperature Bins. *Plotted curves reflect 09:30 LTST ground temperature over 1 MY according to Mars GCM simulation. Steps represent curve fitting using six common levels shared across all sites. Step levels are optimal for given ground temperature curves. Step intervals define sol ranges.*

Once the six optimal temperature bin levels were computed, the Sols at each landing site were assigned to the closest bin and grouped together as shown in Figure 9, an example plot for "Bin 3" environments.

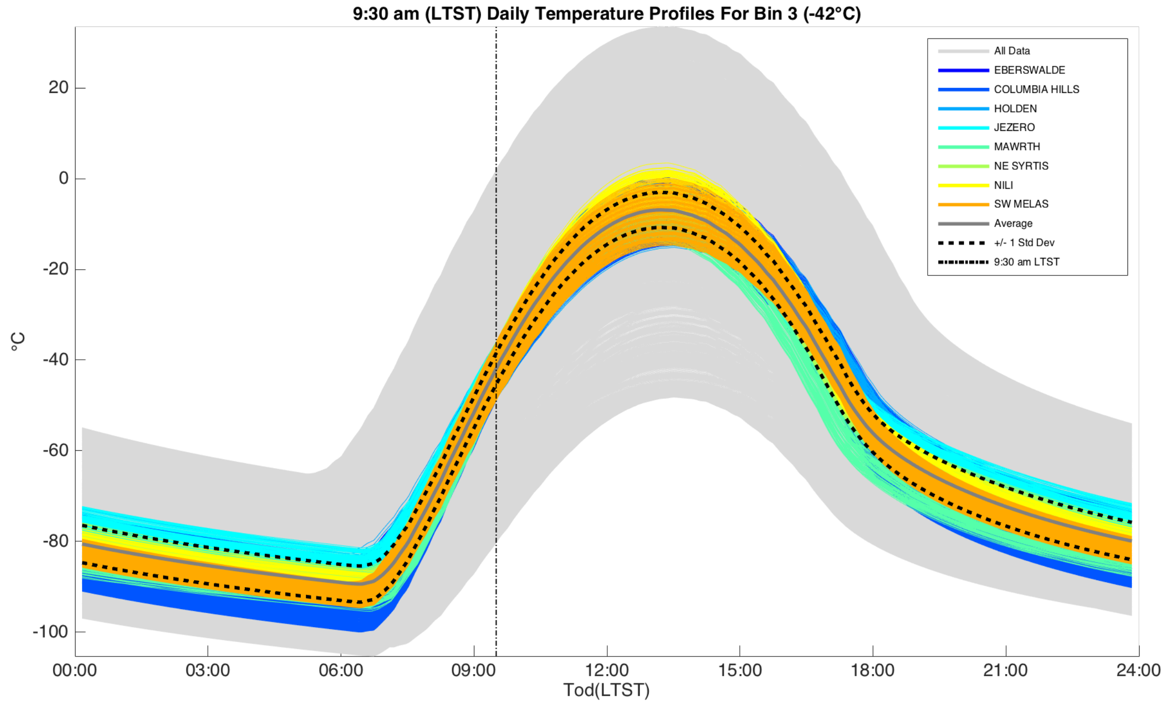

Figure 9. Bin 3 Environment Diurnal Ground Temperature Curves. *Time-of-day ground temperatures for sols at landing sites that fall into environment bin 3.*

Notice that diurnal ground temperature curves are reasonably well correlated, even when taken from different landing sites. From the population of binned Sols we then calculate the corresponding average and +/- 1-sigma diurnal temperature curves. Then the -1 sigma curve was compared back to the population of diurnal temperature curves and we find the Sol within the landing site environment data that most closely matched using the R^2 measure of fitness. Figure 10 shows for all six environment bins the -1 sigma statistical diurnal curve and the best-match diurnal environment from the data set.

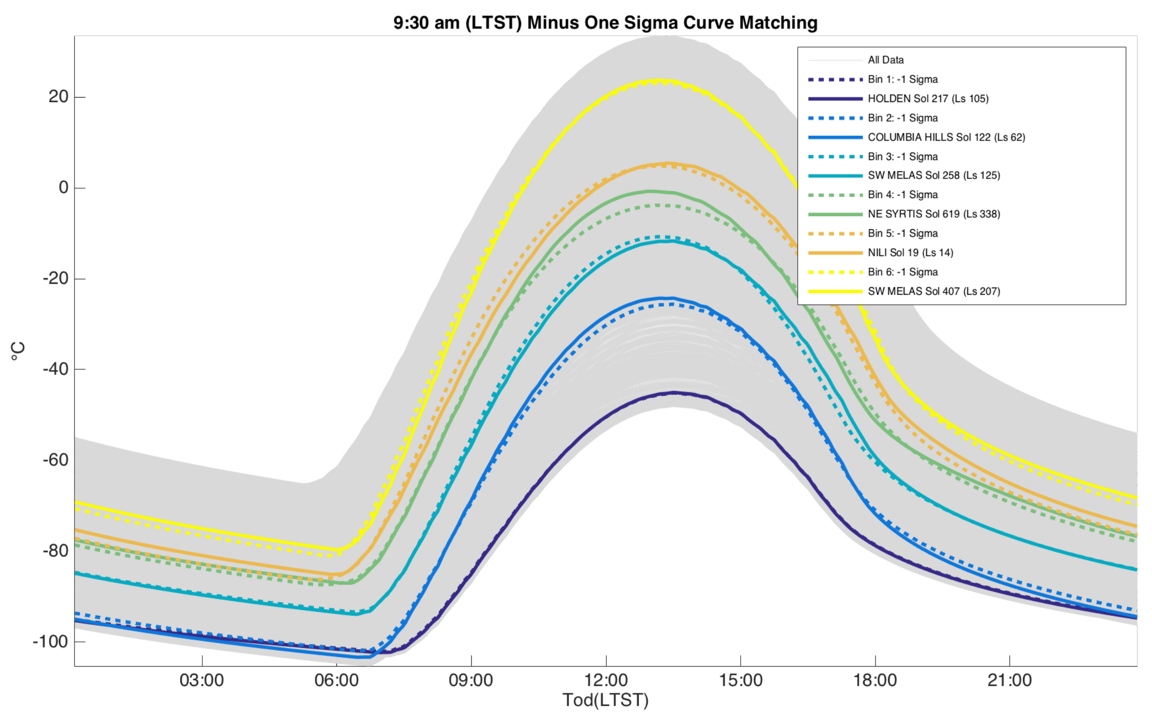

Figure 10. Environment Bin Curve Matching. *Minus 1-sigma statistical dirnal temperatures are matched to an acual ground temperature curve picked from sols at each landing site that fall into the appropriate bin.*

The site environment analysis we present here provides two critical functions, it reduces the widely varied site environments down to just six representative diurnal environments and it defines sol ranges where each environment applies as a simplification of landing site seasonal variations. We can now express landing sites environments *uniquely* for each landing site as a percentage of mission time spent in each of the six discretized environment bins. The table below are environment bin percentages for 1.25 MY missions.

	(coldest) 1	2	3	4	5	(warmes) 6
	1.25 MY Environment Bin %					
Columbia Hills	0%	37%	16%	10%	14%	24%
Eberswalde	26%	21%	10%	7%	10%	26%
Holden	34%	17%	9%	7%	9%	25%
Jezero	0%	0%	22%	65%	12%	0%
Mawrth	0%	10%	15%	41%	34%	0%
NE Syrtis	0%	0%	16%	66%	18%	0%
Nili	0%	0%	18%	60%	22%	0%
SW Melas	0%	26%	23%	11%	17%	22%
BRS	0%	0%	100%	0%	0%	0%

Figure 11. Temperature Bins usage over 1.25 MY. *Percentage of 1.25 MY that each environment bin is used at each landing site, as defined by descritization algorithm.*

D. Sol Type Performance

Finally, we adapt every Sol Type model to be valid under any operational constraint variation over the six environment bins. The six discrete diurnal environments were furnished to Mars 2020 Flight System Thermal group for analysis, who provided preliminary estimates of energy needed for rover survival heating, actuator heat-to-use for 9:30 LTST operations, and unheated hardware operations window constraints. Each Sol Type is then redesigned for each environment bin so that it meets the energy demands on the system. For example, a Sol Type that completes in a single sol's worth of activities in a warm environment might take two sols of activity in a colder environment where more energy is needed for equivalent operations. Figure 12 enumerates Sol Types used in building missions and summarizes their respective durations over the six environment bins. For mobility sol types, the table entry reflects the drive time available, given in hours, for a single sol of drive activity.

Sol Types	Description	Sol Type Duration (# sols) Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6
Remote Sensing Sol Types							
Survey Remote Sensing	Detailed remote sensing of new location, used to inform sol path planning	1	1	1	1	1	1
Workspace Remote Sensing	Detailed remote sensing of Robotic Arm workspace	1	1	1	1	1	1
Robotic Arm Sol Types							
Natural Proximity Science	Investigate [2] surface targets.	2	1	1	1	1	1
Abraded Proximity Science	Abrade surface target and detailed investigation	3	2	2	2	2	2
Sample Coring & Borehole Science	Acquire rock/regolith sample and investigate borehole	4	4	3	3	3	3
Mobility Sol Types		(drive times vary, all are 1 sol duration)					
Long Drive	Blind+Autonav drive modes. Optimized for longest possible drive.	1	2	2.2	3	3	3.25
Medium Drive	Blind+Autonav drive modes with ~1 hour limited remote sensing	1	1.2	1.4	2	2	2.5
Short Drive	Blind-only drive mode, limited to ~30 meters. Remaining resources for remote sensing	0.9	0.9	0.9	1	1	1
Precision Approach	10-meter approach to proximity science "Parking Spot". RSM workspace imaging only.	1	1	1	1	1	1
Precision Approach with Go & Hover	10-meter approach to proximity science "Parking Spot" AND deploy arm for WATSON imaging of workspace,	n/a	n/a	1	1	1	1
Multi-sol Drive	Autonav drive mode without ground-in-the-loop. Scheduled on Constrained sol only.	1	2	2.2	3	3	3.25
Constrained Sol Types							
ISRU	MOXIE full O2 production cycle	1	1	1	1	1	1
MEDA-dedicated	MEDA intensitve observation mode. Can be scheduled on a Constrained Sol	1	1	1	1	1	1

Figure 12. Sol Type performance for Environment Bins.

The bin percentage table (Figure 11) seeds the monte-carlo modeling and defines the probability that a certain environment would be encountered operationally and Sol Types tailored to that environment are then modeled as needed. Therefore, our method of discretizing the landing site environments results in a small set of representative environment bins that simplify thermal modeling for studying operability effects and it gives us a way to *uniquely* express each landing site environment in such a way that we are able to characterize how the landing site environment could affect overall mission performance.

VII. Site-Specific Mission Performance Modeling Results

Results of site-specific mission performance monte-carlo modeling are shown in Figure 13. The chart compares landing site performance, shown as box-and-whisker plots, to the BRS 80th percentile mission result drawn as a green dashed line.

We also report the “deltaSol” value, defined as the difference in unconstrained sols between the site and BRS 80th percentile mission result. And we report the “adjusted Ops Efficiency” for the same 80th percentile mission, which is the Ops Efficiency needed if the 80th percentile mission were performed in 1.25 MY.

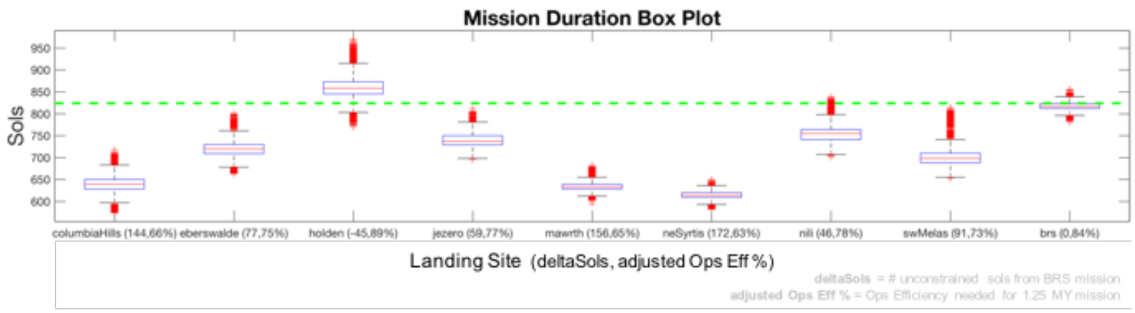

Figure 13. Site-Specific Mission Performance Modeling Results.

VIII. Conclusion

We conclude from site-specific mission performance analysis that the BRS mission does, in fact, define a bounding mission case as compared to the 7 out of 8 candidate landing site. Using the BRS mission case as a benchmark for mission design and development will likely result in mission capabilities that will meet the performance needs of the majority of landing sites. Furthermore, our analysis informs the landing site selection process that the characteristics of one particular landing site may put mission success at risk.

Mars 2020 surface mission performance modeling is an ongoing effort and we expect to make additional model advancements in the course of Mars 2020 Mission Planning. We believe that the approach taken thus far provides a powerful tool for evaluating mission performance and brought important strategic planning advancements to bear on the mission design and development efforts.

Acknowledgments

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References

[1] *Vision and Voyages for Planetary Science in the Decade 2013-2022*, https://solarsystem.nasa.gov/2013decadal/ [online]

[2] *Announcement of Opportunity, Mars 2020 Investigations*, https://nspires.nasaprs.com/external/solicitations/summary.do?method=init&solId=%7BC49E4810-6DE9-9509-E896-EBC006101A9E%7D&path=open [online]

[3] URL for Mars 2020 mission, https://www.jpl.nasa.gov/missions/mars-2020/ [online]

[4] Sharon Laubach, "Calculation of Operations Efficiency Factors for Mars Surface Missions", SpaceOps 2014 Conference, SpaceOps Conferences, (AIAA 2014-1778), http://dx.doi.org/10.2514/6.2014-1778, 12 May 2014.

[5] Mars 2020 Landing Site for Mars Rover Mission, https://marsnext.jpl.nasa.gov/ [online]

[6] URL for MRO mission, https://mars.nasa.gov/mro/ [online]

[7] URL for MAVEN mission, https://www.nasa.gov/mission_pages/maven/main/ [online]